

LIGHTCURVE ANALYSIS FOR ELEVEN MAIN-BELT ASTEROIDS

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Synodic rotation periods were determined for eleven main-belt asteroids: 300 Geraldina, 6.847 ± 0.012 h; 597 Bandusia, 7.6636 ± 0.0008 h; 868 Lova, 41.118 ± 0.011 h; 904 Rockefelleria, 6.826 ± 0.004 h; 964 Subamara, 6.8695 ± 0.0012 h; 965 Angelica, 26.752 ± 0.035 h; 1105 Fragaria, 5.4312 ± 0.0008 h; 1181 Lilith, 15.033 ± 0.003 h; 1197 Rhodesia, 16.060 ± 0.006 h; 1255 Schilowa, 76.275 ± 0.041 h; and 1883 Rimito, 6.475 ± 0.008 h. All the data have submitted to the ALCDEF database.

CCD photometric observations of eleven main-belt asteroids were performed at Command Module Observatory (MPC V02) in Tempe. Images at V02 were taken using a 0.32-m *f*/6.7 Modified Dall-Kirkham telescope, SBIG STXL-6303 CCD camera, and a 'clear' glass filter. Exposure time for all the images was 2 minutes. The image scale after 2x2 binning was 1.76 arcsec/pixel. Table I shows the observing circumstances and results.

Images were calibrated using a dozen bias, dark, and flat frames. Flat-field images were made using an electroluminescent panel. Image calibration and alignment were performed using *MaxIm DL* software.

The data reduction and period analysis were done using *MPO Canopus* (Warner, 2017). The 45x30 arcmin field of the CCD typically enables the use of the same field center for three consecutive nights. In these fields, the asteroid and three to five comparison stars were measured. Comparison stars were selected with colors within the range of $0.5 < B-V < 0.95$ to correspond with color ranges of asteroids. In order to reduce the internal scatter in the data, the brightest stars of appropriate color that had peak ADU counts below the range where chip response becomes nonlinear were selected. The *MPO Canopus* internal star catalogue was useful in selecting comp stars of suitable color and brightness.

Comp star magnitudes were derived from a combination of CMC15 (Muñoz et al. 2014), APASS DR9 (Munari et al. 2015), and GAIA1 G (Sloan $r' = G + 0.066$ for stars of asteroidal color) catalogues to set the zero-points each night. In most regions the Sloan r' data sources for brighter stars yielded very similar magnitudes (within about 0.05 mag total range), so mean values rounded to 0.01 mag precision were used.

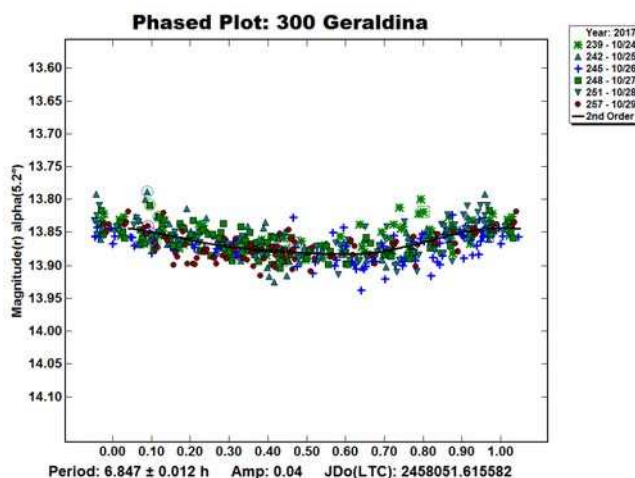
This careful adjustment of the comp star magnitudes and color-indices allowed the separate nightly runs to be linked often with no zero-point offset required, or shifts of only a few hundredths of a magnitude in a series.

A 9-pixel (16 arcsec) diameter measuring aperture was used for asteroids and comp stars. It was typically necessary to employ star subtraction to remove contamination by field stars. For the asteroids described here, I note the RMS scatter on the phased lightcurves, which gives an indication of the overall data quality including errors from the calibration of the frames, measurement

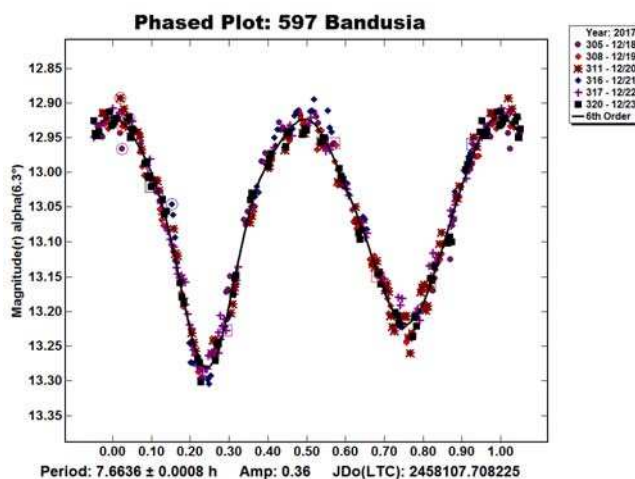
of the comp stars, the asteroid itself, and the period-fit. Period determination was done using the *MPO Canopus* Fourier-type FALC fitting method (cf. Harris et al., 1989).

In most cases, asteroids were selected from the CALL website (Warner, 2011) using the criteria of magnitude greater than 14.5 and quality of results, $U < 3$ -. The Asteroid Lightcurve Database (LCDB; Warner et al., 2009) was consulted to locate previously published results. All of the new data for these eleven asteroids may be found in the ALCDEF database.

300 Geraldina is a main-belt asteroid that was discovered in 1890 by Auguste Charlois at Nice. Five consistent periods, all between 6.81 h and 6.86 h were found in the LCDB. The most recent of these is 6.850 ± 0.0041 h, determined by Waszczak et al. (2015). In 2017 October, 518 observations on six nights were obtained to determine the rotation period of 6.847 ± 0.012 h, which agreed with the previously published results. The amplitude is only 0.04 ± 0.02 mag; the RMS scatter on the fit shown in the phased plot is 0.018 mag.



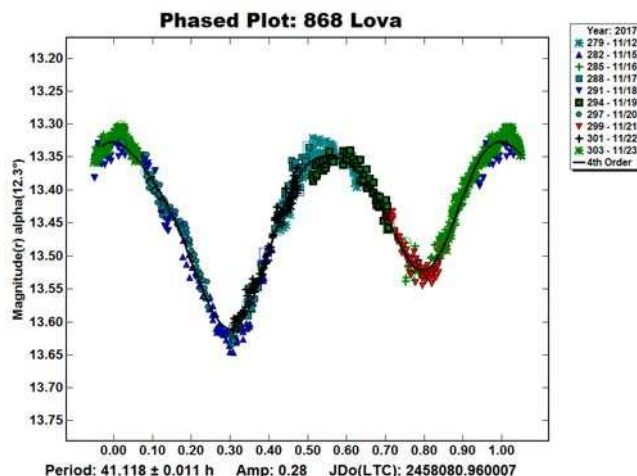
597 Bandusia. Max Wolf discovered this Eunomia-family asteroid in 1906 at Heidelberg. Two periods were found: Behrend (2002) shows 11.50 h, and Garlitz (2013) computed 15.340 h.



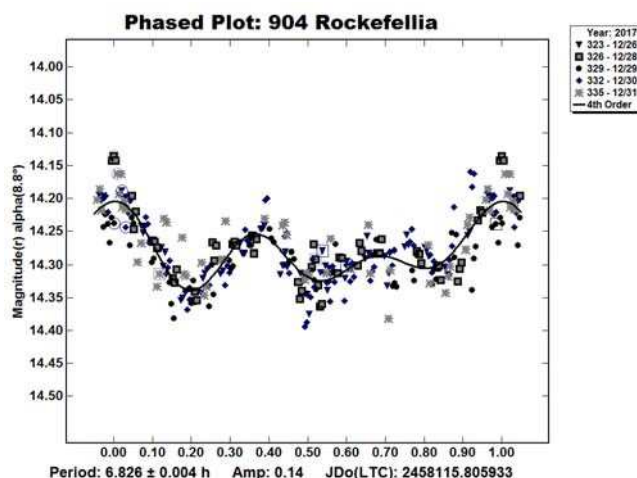
A total of 454 images were gathered during six nights in 2017 December, producing a rotational period of 7.6636 ± 0.0008 h. This result disagrees with Behrend's period and is roughly half of

Garlitz's result. The amplitude is 0.36 ± 0.02 mag. The RMS scatter on the fit is 0.016 mag.

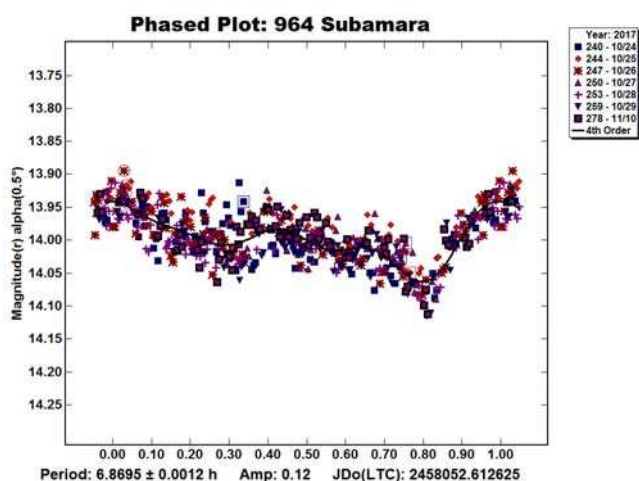
868 Lova was discovered by Max Wolf at Heidelberg in 1917. Three entries for the period were found in the LCDB. Warner (2001) and Warner (2006) both show a period of >24 h. Behrend (2005) computed 41.3 h. A total of 857 observations during ten nights in 2017 November were made to produce a lightcurve for 868 Lova. The resulting rotational period is 41.118 ± 0.011 h, which agrees well with Behrend's result. The full amplitude is 0.28 ± 0.01 mag; the RMS scatter of the fit is 0.014 mag.



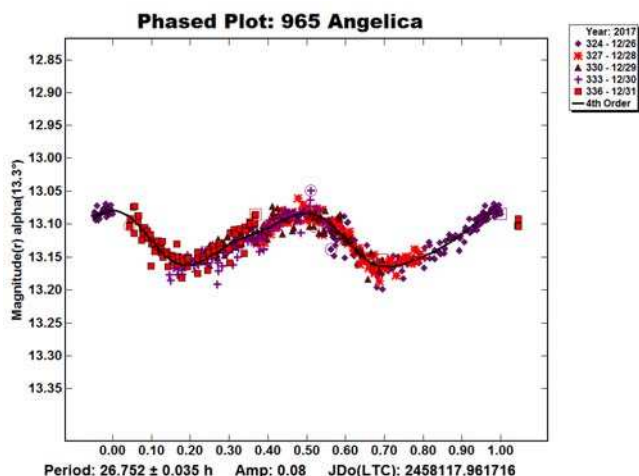
904 Rockefelleria. Max Wolf at Heidelberg discovered this outer-belt asteroid in 1918. Fauvaud (2013) determined a period of 5.82 ± 0.01 h and Behrend (2014) computed 12.72 ± 0.03 h. Five nights in 2017 December and 285 observations were sufficient to determine a rotational period of 6.826 ± 0.004 h, disagreeing with previously published results. The amplitude is 0.14 ± 0.03 mag, and the RMS error on the fit is 0.030 mag.



964 Subamara. This outer-belt asteroid was discovered in 1921 by Johann Palisa at Vienna. *Two periods have been documented.* Folberth *et al.* (2012) obtained a period of 6.864 ± 0.004 h and Alkema (2013) computed 6.868 ± 0.001 h. On seven nights in 2017 October and November, 555 images of 964 Subamara were secured. The lightcurve shows a period of 6.8695 ± 0.0012 h, in accordance with the two published period solutions. The RMS scatter on the fit is 0.025 mag. The amplitude is 0.12 ± 0.03 mag.



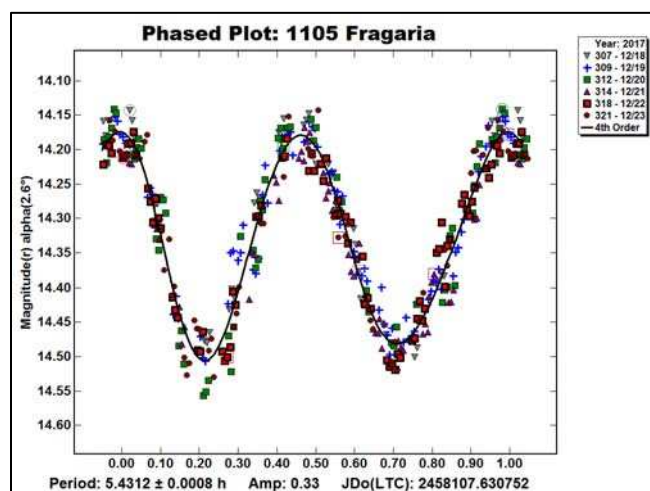
965 Angelica is an outer-belt asteroid with high eccentricity discovered by Johannes Hartman at La Plata in 1921. Its high inclination brought it to a declination of greater than $+50^\circ$ during the observing interval. The only published rotational period is that of Behrend (2006), who shows a result of 17.772 ± 0.007 h. Observations of 965 Angelica were made on five nights in 2017 December, until 530 data points were acquired. The double-mode period is 26.752 ± 0.035 h, which is larger than Behrend's determination by a 3/2 ratio. The amplitude is 0.08 ± 0.01 mag, and the RMS error on the fit is 0.012 mag. The "split halves" feature in *MPO Canopus* was used to assess the validity of the single-mode solution of 13.335 h. The mismatch in the phased halves illustrated that the double-mode period is the preferred solution.



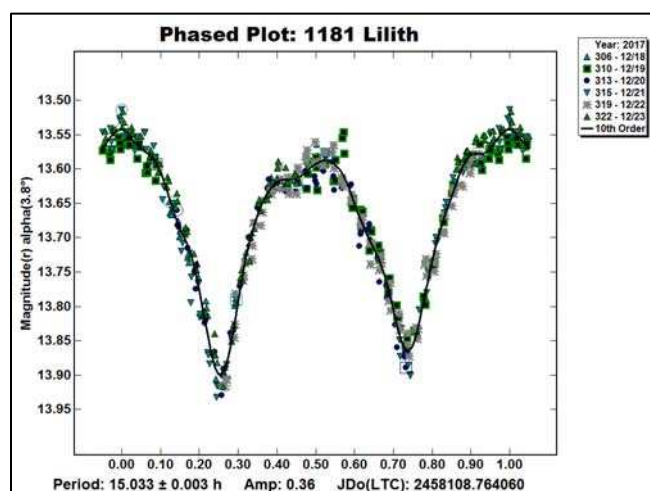
1105 Fragaria is an Eoan asteroid that was discovered in 1929 by Karl Reinmuth at Heidelberg. Only one period is found in the LCDB, that of Barucci *et al.* (1994) who computed 10.88 h. A total of 385 images were obtained during six nights in 2017 December. These data produced a rotational period of 5.4312 ± 0.0008 h. This period is roughly half of Barucci's result. The amplitude is 0.33 ± 0.03 mag., and the RMS scatter of the fit is 0.029 mag.

Number	Name	2017/mm/dd	Pts	Phase	L_{PAB}	B_{PAB}	Period (h)	P.E.	Amp	A.E.	Grp
300	Geraldina	10/24–10/29	518	5.2, 3.3	44	0	6.847	0.012	0.04	0.02	MB-O
597	Bandusia	12/18–12/23	454	6.4, 5.9	92	13	7.6636	0.0008	0.36	0.02	EUN
868	Lova	11/12–11/23	857	12.3, 7.3	73	-6	41.118	0.011	0.28	0.01	MB-O
904	Rockefellia	12/26–12/31	285	8.8, 8.3	103	-19	6.826	0.004	0.14	0.03	MB-O
964	Subamara	10/24–11/10	555	0.5, 0.1, 6.9	32	1	6.8695	0.0012	0.12	0.03	MB-O
965	Angelica	12/26–12/31	530	13.3, 13.2	101	25	26.752	0.035	0.08	0.01	MB-O
1105	Fragaria	12/18–12/23	385	2.6, 3.0	87	-7	5.4312	0.0008	0.33	0.03	EOS
1181	Lilith	12/18–12/23	447	3.8, 6.5	80	0	15.033	0.003	0.36	0.02	MB-M
1197	Rhodesia	12/26–12/31	359	2.5, 4.0	93	-5	16.060	0.006	0.27	0.01	MB-O
1255	Schilowa	11/12–11/23	880	1.3, 0.4, 3.6	53	1	76.275	0.041	0.26	0.01	MB-O
1883	Rimito	11/12–11/19	331	12.7, 9.3	60	-13	6.475	0.008	0.04	0.02	MB-I

Table I. Observing circumstances and results. The phase angle (α) is given at the start and end of each date range, unless it reached a minimum or maximum, which is then the second of three values. L_{PAB} and B_{PAB} are each the average phase angle bisector longitude and latitude (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009).



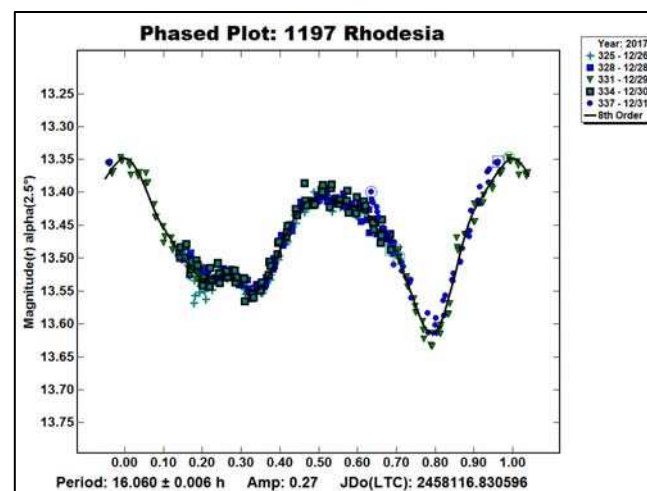
1181 Lilith was discovered by Benjamin Jekhovsky at Algiers in 1927. The only rotational period that has been published is that of Ferrero (2014), who found 15.04 ± 0.01 h.



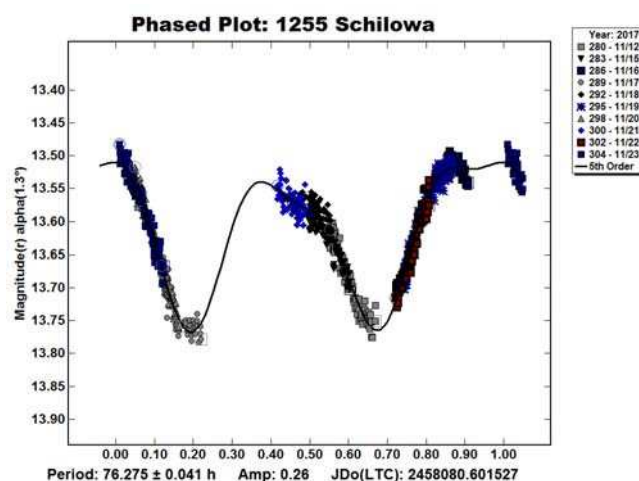
Observations of 1181 Lilith were made on six nights in 2017 December, and 447 data points were obtained. Due to the sharp minima, a 10th-order curve fit was used. The resulting period is 15.033 ± 0.003 h, in accordance with Ferrero's determination. The amplitude of the lightcurve is 0.36 ± 0.02 mag. The fit has an RMS scatter of 0.017 mag.

1197 Rhodesia Cyril Jackson discovered this outer-belt asteroid in 1931 at Johannesburg in 1931. Two period determinations have been performed. Binzel (1987) found a period of 15.89 h while Behrend (2005) obtained 16.062 ± 0.003 h.

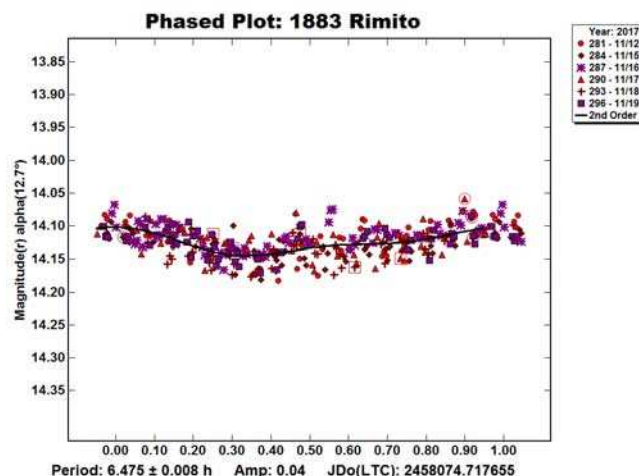
Due mostly to clouds and proximity of the moon, observations were limited to only five nights in late 2017 December, during which 359 images were gathered. As a result of the brief observation interval and the commensurate nature of the period, the lightcurve has less coverage than desired. The period of 16.060 ± 0.006 h agrees with previous determinations. A lightcurve amplitude of 0.27 ± 0.01 mag and an RMS scatter of 0.012 mag were computed.



1255 Schilowa was discovered in 1932 by Grigory Neujmin at Simeis. The most recent period determination of Behrend (2006) is 29.7 ± 0.1 h. This asteroid's long period required a significant observation interval. On ten nights in 2017 November, 880 data points were captured to produce a rotational period of 76.275 ± 0.041 h., disagreeing with Behrend's result. The amplitude is 0.26 ± 0.01 , and RMS scatter of the fit is 0.013 mag.



1883 Rimito. This inner-belt asteroid has both high inclination and eccentricity. It was discovered in 1942 at Turku by Yrjö Väisälä. The LCB shows no entries for this asteroid. On six nights in 2017 November, 331 images of 1883 Rimito were obtained. The very low amplitude initially led to an indeterminate period solution. Brian Skiff (private communications) used the 0.7-m f/8 telescope at the Lowell Observatory Anderson Mesa Station (MPC 688) to gather 85 data points on three consecutive nights, also in 2017 November. His analysis produced a period of 6.492 ± 0.013 h, with an RMS scatter on the fit of 0.005 mag. Revisiting the data from the six nights at V02, a similar rotational period of 6.475 ± 0.008 h was computed. The amplitude is 0.05 ± 0.02 mag. RMS scatter of the fit is 0.019 mag., which is significant relative to the amplitude.



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LIGHTCURVE ANALYSIS OF TEN ASTEROIDS FROM RMS OBSERVATORY

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CCD images of ten asteroids were taken from 2017 August 24 to November 14 for the purpose of determining the asteroids' synodic rotation periods: 2353 Alva, 2440 Educatio, 2633 Bishop, 4911 Rosenzweig, (6490) 1991 NR2, (6693) 1986 CC2, (11745) 1999 NH3, (20885) 2000 WD2, (33982) 2000 NQ23, and (171576) 1999 VP11.

CCD photometric observations of ten asteroids were made from the RMS Observatory (W25) from 2017 August 24 to November 14. The observations were made with a 0.35-m Schmidt-Cassegrain operating at $f/7.6$ and Atik One 6.0 CCD. The camera was binned 3x3, which gave an image scale of 1.05 arcseconds per pixel. Exposures were unfiltered and varied from 30 to 240 s.

The images were calibrated (bias, dark, and flat) with *AstroImageJ* (Collins and Kielkopf, 2013). Differential photometry measurements were made in *MPO Canopus* (Warner, 2017) using the FALC routine (Harris *et al.*, 1989) to derive the asteroid synodic periods. The StarBGone utility in *MPO Canopus* was applied to measure images when asteroids were located in the vicinity of stars. The *MPO Canopus* Comp Star Selector utility was employed to select comparison stars of near solar-color for differential photometry for all asteroids. R band magnitudes were taken from the CMC-15 catalog (Munos, 2017) and were chosen to best match the unfiltered CCD measurements.

Table I lists the observing circumstances and the analysis results.

2353 Alva. This main belt asteroid was listed as a lightcurve photometry opportunity (Warner *et al.*, 2017a). A search of the asteroid lightcurve database (LCDB; Warner *et al.* 2009) did not find any previous period. Analysis showed a bimodal period of 62.6 h. A monomodal solution of 31.3 h is indicated in the period spectrum plot, but this is probably an alias.

